Magnetic property of dislocations in antiferromagnetic NiO single crystalline thin film

I.Sugiyama[1], S. Kobayashi[2], N. Shibata[1], Y. Ikuhara[1, 3], T. Yamamoto[2,3, 4]

[1]Institute of Engineering Innovation, University of Tokyo, Tokyo 113-8656, Japan
[2]Department of Advanced Materials Science, University of Tokyo, Chiba 277-8561, Japan
[3]Nanostructures Research Laboratory, Japan Fine Ceramics Center, Nagoya, 456-8587, Japan
4Department of Quantum Engineering, Nagoya University, Nagoya 464-8603, Japan

Dislocations are one-dimensional lattice defects in crystals. The dislocations can be positively used for deformation or reinforcement of materials, because they have significant effect on mechanical properties. In contrast, they are often harmful for electric and magnetic properties because they disorder the lattice locally. In this reason, many works devoted efforts to eliminate dislocations in electric and magnetic materials.

On the other hand, there are some reports which willingly utilized dislocations in electrical use [1-3]. For example, conductive nano-wires were made by diffusing Ti into dislocation cores in Alumina; typical insulating material [1].

In this study, these techniques are applied for providing magnetic properties. The aim is to build in ferromagnetic nano-wire in undoped dislocations by utilizing disorder of the structure. For this purpose, magnetic property of dislocations in NiO, which is typical antiferromagnetic material, is investigated.

The NiO single crystalline films were grown on the0.05wt%-Nb doped $SrTiO_3$ (001) single crystal substrates with atomically flat surface by pulsed laser deposition (PLD). KrF excimer laser (248nm) was used at 10Hz for ablating NiO polycrystalline target. The substrate was kept at room temperature, and the environment was O_2 ~10^{-5} Torr. The film thickness was controlled by adjusting total pulse counts to be about 100nm. After deposition, the samples were annealed at 1100°C for 0.5h in air.

Lattice parameters were measured by θ-2θ scan of X-ray out-of-plane diffractometry (XRD, ATX-G, Rigaku Co., Japan). The dislocations in the obtained films were investigated by conventional transmission electron microscopy (c-TEM) method (JEM-2010HC, JEOL Ltd.), and the atomic structure was observed by high-resolution TEM (HRTEM) (EM-002BF, TOPCON Co.) and HAADF-STEM (JEM-2100F, JEOL Ltd.) equipped with a spherical aberration corrector (CEOS GmbH.). All TEMs were operated at 200kV. The surface structure and magnetic property were investigated by atomic force microscopy (AFM) and magnetic force microscopy (MFM) (JSPM-5200, JEOL Ltd.).

c-TEM observation in the plan-view direction revealed that dislocations are successfully introduced into single crystalline NiO thin film as shown in Fig. 1. The dislocation lines of all dislocations are parallel to [001], which is the film growth direction. By weak beam (g-3g) method, the Burgers vectors of the dislocations were classified into two types. One is edge dislocation of Burgers vector **b** = a/2[100] + a/2[010], where *a* is the lattice parameter of NiO, and the other is composite dislocation of Burgers vector **b** = a/2[100] + a/2[001]. The dislocation density was estimated to be ~5×10^{12} /m^2 by TEM bright field images.

Figure 2 shows the AFM topography image of the NiO thin film surface. The image shows that there are many dips at the surface of the thin film. The dip density was estimated to be ~$5x10^{12}$ /m^2. Because the dislocation density corresponds to the dip density and bend contour is observed around the dislocations (Fig. 1), it can be concluded that the dips in AFM topography image correspond to the dislocations.

MFM observation was carried out under zero-magnetic field after magnetizing the sample and a cantilever. Figure 3 shows the MFM phase image of the same area to Fig. 2. It is noted that the repulsive force is observed around the dips. Because the non-magnetic forces are all attractive, the repulsive force is mainly consists of magnetic force component. Hence, we succeeded in making not antiferromagnetic phase locally at the dislocations in the antiferromagnetic NiO single crystalline thin film.

In this study, NiO thin film with threading dislocations was prepared by PLD method. The dislocations show anomalous magnetic property different from that of the bulk NiO.

Reference

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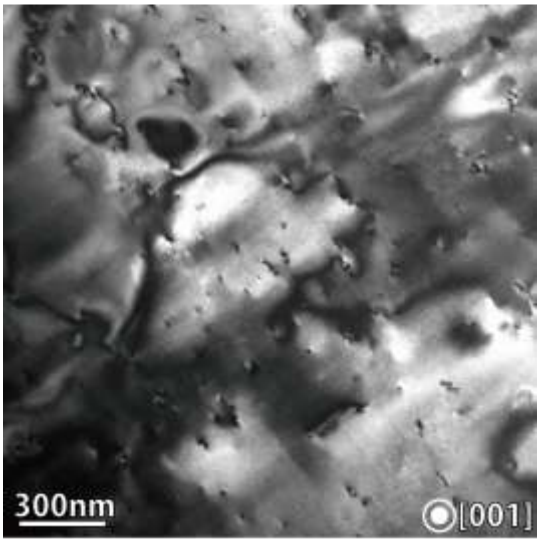

Fig.1. TEM bright field image of NiO thin film

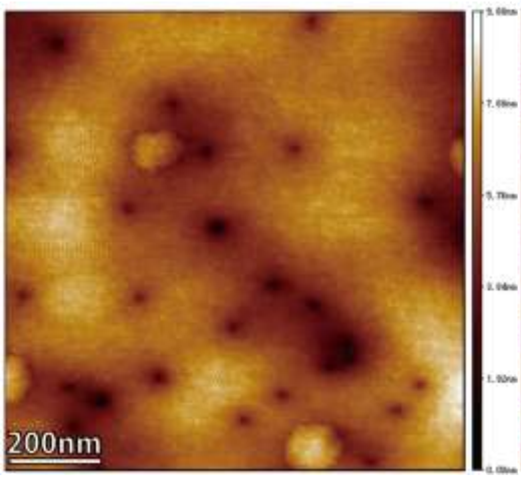

Fig.2. AFM topographic image

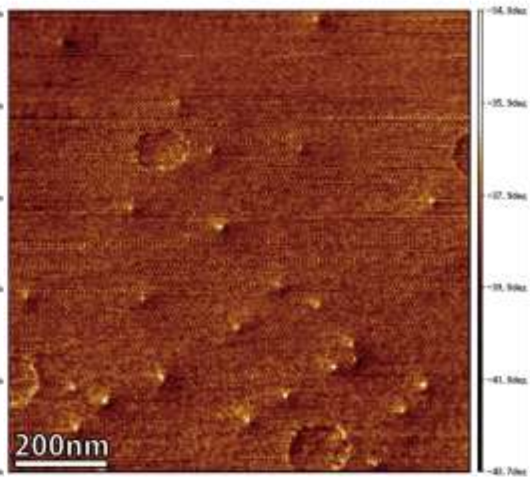

Fig.3. MFM phase image